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# 3D PASSAGE NAVIGATION UNDER UNKNOWN ENVIRONMENTS BASED ON DISTANCE FIELD SPACE MODEL

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***Abstract* - The navigation problem of robot is one of the main themes to deal with conflicts or interferences between obstacles and the robot itself. In this case, while the robot avoids obstacles on the space, the passage route should be determined efficiently. In order to solve problems above, we have come up with the distance field space model (DFM) and then, under known environment, we have presented the distance field A*algorithm for passage route path search. In this research, the method of performing the 3-dimensional passage route path search of robot under unknown environment is proposed. It is shown that the authors can build the distance search model that does not need space division by taking into account of sensor information to a distance field space model, and constructing this information as virtual obstacle information.***

## I. INTRODUCTION

By exploiting the Distance Field Space Model (DFM)[1], a passage route search problem under known environment where the information required about motion work space is given to the robot, is well formulated as the Distance Field A* algorithm (DF-A*) and verified by numerical simulation[2]. The authors showed that a distance datum of the distance field data for any reference point outside the obstacles can be translated as a fuzzy measure representing an estimate of the distance between the point and the obstacles. In this paper, the authors deal with a passage route search problem under unknown environment where the information required about motion workspace is not given beforehand to the robot.

As for researches on unknown environment, most route search algorithms are carried out on real time control with sensors and actuators and therefore, they either use a simple world model of limited functions or nothing [3],[4]. On the contrary, there is a more advanced real time control with prediction under unknown environment. Oriolo, et al. proposed a new passage navigation algorithm where surrounding environment is predicted according to the sensor data of the moving robot and then its succeeding route is updated by the prediction [5]. In order to construct a world model, the prediction control method divides the passage space to a set of 2 dimensional meshes and, assigns and updates the weight of certainty that no obstacle is there to each cell as a fuzzy membership datum which is iteratively drawn from the sensor data. Similarly, Aradio, et al. implemented binary-tree meshing which also requires another kind of space division [6].

In this paper, while fundamentally following the mechanism of Oriolo, et al.'s method, our new passage route search algorithm requires no space division, by importing the sensor data to the DFM and representing the environment of the motion space as a DFM model.

## II. NAVIGATION MODEL

Fundamentally, the authors follow Oriolo, et al.'s approach. However, our method is to be considered in computer simulation and not realized by real motion of robots like NOMAD 200 produced by Normadic Technology Inc. as used in Oriolo, et al.'s approach. As shown in the Figure 1, the navigation model under unknown environment is composed of two phases, the one of which is that of "building environment" based on sensing for inference of the environment and the other is that of "robot navigation", where passage route planning and robot navigation are conducted according to the environment updated. These are detailed as follows.

### *A. Building-environment phase*

(1) Sensing (Simulation)

As NOMAD 200, super sonic sensors infer the distance between the robot and the surrounding obstacles according to the sensing model of range measurement. In the case of unknown environment, only the estimate by inference is taken for consideration.

(2) Estimation of environment

According to the results of the sensing and the DFM, new spatial information is constructed as "feasible region of motion" and "infeasible region of motion" which is to be detailed in next section.

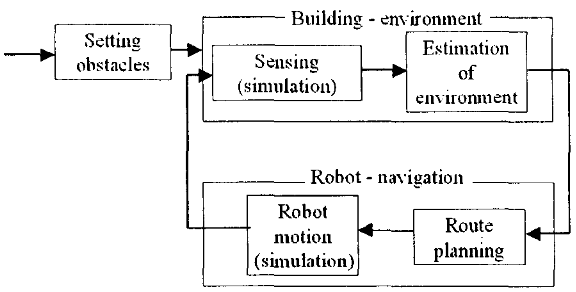



Figure 1. Navigation model

***B. Robot-navigation phase***

(1) Route planning

This planning determines an estimated optimal route from the present robot position to the goal, using inferred spatial information, especially on the infeasible motion area. In this planning, the inferred infeasible motion area is taken as the present known environment and the DF-A* algorithm is well applied for searching the route, which is given as a path composed of a connected series of linear segments [2]. When no route is found here, the navigation stops as infeasible.

(2) Robot motion (Simulation)

First, the robot moves toward the end of the first segment along the segment as far as the end is reached. In the meantime, if the robot collides with an obstacle, then the point is taken as next sensing point, or else if the end point is the goal, then the robot stops there and the passage completes successfully, or else check whether the point is inside the feasible motion area or not. If the end is outside, then the point is taken as next sensing point, or else do the same operation for next segment.

Finally, while continuing robot motion, it reaches the goal and completes the simulation, or stops temporarily at the next sensing point in the latter case, the simulation is back to the building-environment phase and continues.

## III. CONSTRUCTION OF THE SENSING MODEL

In this section, assuming supersonic sensors are allocated in the equal angular intervals along the cylindrical boundary of the robot, a range sensing model of the sensor system is constructed. First of all, Oriolo, et al.'s model is roughly reviewed. Then, the authors' model is introduced as a new model based on the DFM.

***A. Oriolo, et al.'s model***

In Oriolo, et al.'s model, the credibility of the estimated range where some obstacle exists is considered as follows, according to the physical characteristic of a supersonic sensor of the sensor system.

(1) The existence is confined to the angular width ($\pm\Delta\theta$) with respect to the emitted beam axis. That is, the intensity of a reflected beam decrease suddenly as the direction gets apart from the center axis and the existence is taken in consideration only within the directions at most $\Delta\theta$ degree apart from the axis.

(2) Even if the range signal $r$ is given, the existence is taken as ambiguous in the width ($\pm\Delta r$) with the center $r$.

(3) No reflected beam is available for the obstacles apart more than the distance $\rho_V$ from the sensor.

Then, Oriolo, et al. two fuzzy sets : "Occupied" which means the point inside obstacles and "Empty" which means the point outside the obstacles, and these membership functions are defined in a cylindrical coordinate.

***B. A new sensing model based on the DFM***

Translating the DFM as the fuzzy space model, the similar concept to Oriolo, et al.'s sensing model is implemented by using primitive objects of the DFM. The authors introduced two kinds of sensing models, an "optimistic model" which stands optimistically for the robot, and a "pessimistic model" on the other hand. Note that in either case, no primitives are generated for a sensor measuring the range $r > \rho_V$.

(1) Optimistic model

As primitive objects representing the optimistic fuzzy sets, the "Optimistically occupied" $\Delta O$ and "Optimistically empty" $\Delta E$ as shown in Figure 2, are defined respect-ively. This interpretation is valid because the distance measure (the distance datum of the distance field data), can be treated as a fuzzy membership function [2]. Incidentally, the term "optimistic" is applied to the treatment that the obstacles possibly exists only in the area $\rho > r$ where $r$ is the sensed range, and its inside ($\rho < r$) is treated as the Empty region.

(2) Pessimistic model

As primitive objects representing the pessimistic fuzzy sets, the "Pessimistically occupied" $\delta O$ and "Pessimistically empty" $\delta E$ as shown in Figure 3, are defined respectively. In this case, the occupied region is taken excessively large as $\delta O$ and on the contrary, the empty region is excessively small as $\delta E$, which means pessimistic for the robot.

## IV. ESTIMATION OF THE ENVIRONMENT AND ROBOT NAVIGATION BASED ON THE DFM

By inference of environment based on the sensing models, the passage environment is estimated. In this section, the inference algorithm for the infeasible region of motion $O_k$ and feasible region of motion $E_k$, and that of the robot navigation are discussed.

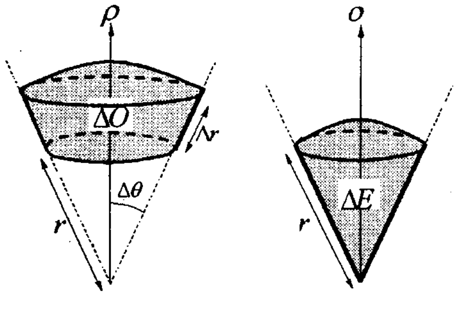



Figure 2. Optimistic model

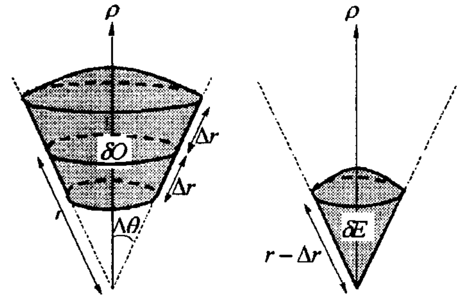



Figure 3. Pessimistic model

*A. Estimation algorithm for the regions $O_k$ and $E_k$*

First of all, at the present position of robot, all the sensed data $(\Delta O, \Delta E)$ and $(\delta O, \delta E)$ are stored in time series. Moreover, at any sensing point $k$, sensors more than one are assumed participating in sensing. That is, from the start to the point $k$, let $n$ -sets of data $(\Delta O_i, \Delta E_i)$, $(\delta O_i, \delta E_i)$, $i = 1 \sim n$ be stored in the sensing database. Then, at the point $k$, the infeasible region of motion $O_k$ and feasible region of motion $E_k$ are estimated as follows.

$$O_k \leftarrow \phi; \qquad (i = 1 \sim n)$$

$$O_k \leftarrow O_k \cup \Delta Oi - \Delta E_i \quad = \Delta O_i \cup (O_k \cap \Delta^c E_i) \quad (1)$$

Thus, the region $O_k$ is estimated optimistically for the robot.

$$E_k \leftarrow \phi; \qquad (i = 1 \sim n)$$

$$E_k \leftarrow E_k \cup \delta E_i - \delta O_i \quad = \delta E_i \cup (E_k \cap \delta^c O_i) \quad (2)$$

On the contrary, the region $E_k$ is estimated pessimistically for the robot.

*B. Navigation algorithm*

Since the outline of the algorithm is already described in the 2nd section, it is not detailed here. That is, the navigation phase is composed of the passage route planning and the motion simulation of the robot based on the planning. In the route planning, under the given region $O_k$, an optimal route from the point $k$ to the goal is searched by use of the route search algorithm under known environment. Since this route is an estimate of feasible optimal route, the infeasible region $O_k$, then, its corresponding complement $O_k^c$ of feasible region is taken optimistically. Then, according to the solution path given in the planning, the robot is simulated to move by 1 segment step at maximum on the path, while the robot is confined in the region $E_k$. Thus, the region $E_k$ is estimated so narrowly as re-trys due to collision with obstacles do not often occur.

## V. NUMERICAL SIMULATION AND DISCUSSIONS

The kernel of the simulation program is the module handling the sensing data. In this program, a set of sensing data given by one shot sensing of one sensor is stored in a structured cell (named Range) and the whole time series of the data are managed by the chain of the Range cells. Then, the fuzzy distance measures for $O_k$ and $E_k$ are easily computed. That is, for example, the distance measure at a point $P$ for the obstacle $O_k$ (or $E_k$) is given by the following algorithm according to the eqs. (1) (or eqs. (2)).

**[Fuzzy distance measure for $O_k$ at $P$]**

[Step 1] On the working fields $dO_i$ and $dE_i$ of the i-th Range, the fuzzy distance measures for $\Delta O$ and $\Delta^c E$ are stored respectively.

[Step 2] For $i = 2 \sim n$,

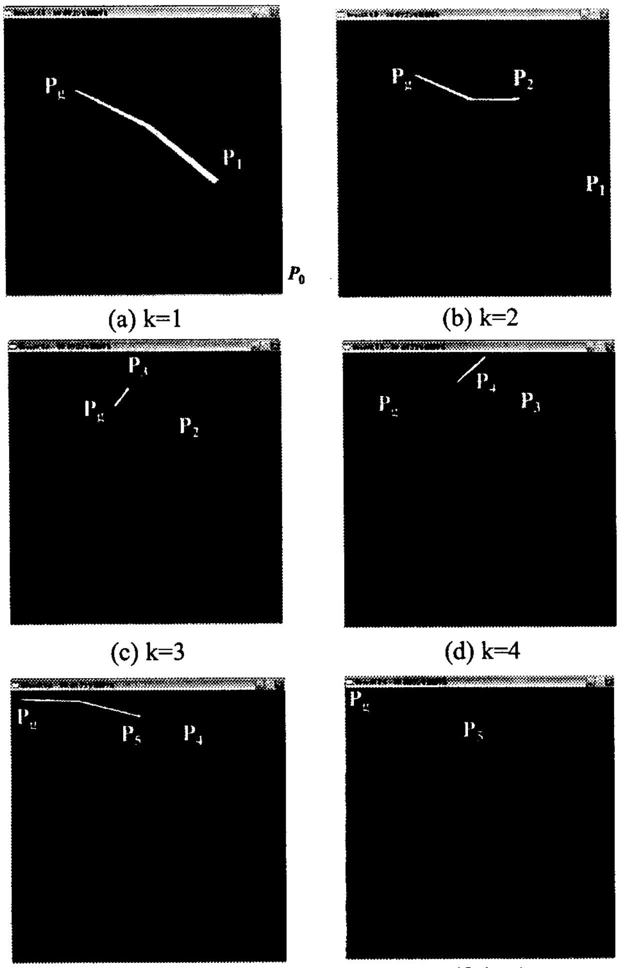
$$dO_i \leftarrow \max(dO_i, \min(dO_{i-1}, dE_i)).$$

[Step 3] The solution is found on $dO_n$.

Similarly, by interchanging $O$ with $E$, we have another algorithm for [Fuzzy distance measure for $E_k$ at $P$].

Then, the numerical experiment is conducted as the same values as in the case of known environment (moreover, let the sensor parameters $\Delta\theta = 15$ degree, $\Delta\gamma = 1$ and $\rho_V = 10$) [2].

While considering the environment unknown for the same domain, in the Figures 4 (a) ~ (f), the case is representing the process how to plan the passage routes and how to navigate the robot according to the sensing model and the navigation algorithm. You may read Figure 4 as follows. In each figure ($k = 1 \sim 6$), a path shown in red & white, means the resulted path $L_k$ of the route search from the $P_{k-1}(P_0 = P_s)$ to the goal $P_g = P_6$ based on the estimate of infeasible region $O_k$ of motion, while assuming the environment is known.



(a) k=1 (b) k=2 (c) k=3 (d) k=4 (e) k=5 (f) k=6

Figure 4. Navigation for unknown environment

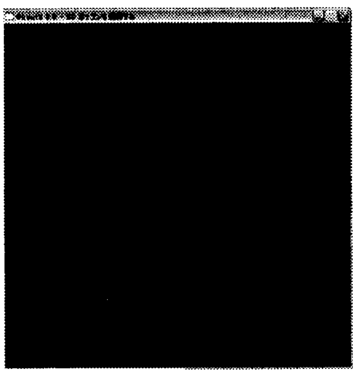


Figure 5. Resulted path under unknown environment

Incidentally, the $O_k$ is estimated by updating the $O_{k-1}$ using the sensing data at the point $P_{k-1}$, which means the application of the eqs. (1). In the next step, the passage route, shown in red, on the path $L_k$ is solved according to the navigation algorithm based on the region $E_k$. As updating $O_k$, the region $E_k$ is estimated by updating the $E_{k-1}$ using the sensing data at the point $P_{k-1}$, which means the application of the eqs. (2). Figure 5 shows the resulted path under unknown environment.

## VI. CONCLUSION

By exploiting the fact already shown by the authors that the DFM is interpreted as a fuzzy space model under known environment and the passage route problem is solved by the DF-A* algorithm, the authors, based on the DFM, developed a new search algorithm of the passage route and a robot navigation algorithm under unknown environment.

(1) Results

Oriolo, et al.'s navigation method under unknown environment can be replaced by a simpler and more flexible method based on the DFM. The major point is due to the superior characteristic of the DFM that it can be interpreted as a fuzzy space model and needs no division of space.

(2) Future works

Experiment and verification of the method using real robots are left as future works.

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